

**INVESTIGATIONS INTO
THE RADIOACTIVE DECAY OF
SOME LEAD AND THALLIUM
ISOTOPES**

Construction of a Mass Separator

**Systematics of Energy Levels
and Multipole Transitions**

By

GÖRAN ANDERSSON

UPPSALA 1957

ALMQVIST & WIKSELLS BOKTRYCKERI AB

Uppsala.

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THE RADIOACTIVE DECAY OF
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Construction of a Mass Separator

Systematics of Energy Levels
and Multipole Transitions

INAUGURAL DISSERTATION

by

GÖRAN ANDERSSON

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BY DUE PERMISSION OF THE FACULTY OF SCIENCE
OF THE UNIVERSITY OF UPPSALA
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UPPSALA 1957

ALMQVIST & WIKSELLS BOKTRYCKERI AB

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To my Mother and my Wife

PREFACE

The present dissertation is based on work performed at the Gustaf Werner Institute for Nuclear Chemistry, Uppsala, with financial support from the Swedish Atomic Energy Commission and accounted for in six separate review articles to be summarized in this introductory paper.

It is impossible to enumerate here all those to whom I owe a debt of gratitude for cooperation and encouragement during the long period of my research. Some of my collaborators appear as co-authors of the separate articles. Referring moreover to the acknowledgements made in those articles I restrict myself to mentioning particularly a few persons who in various respects have facilitated the work as a whole.

I have had the privilege of working under the directorship of Professor The Svedberg. In spite of the considerable freedom he left me in the choice of research field he has continuously followed the progress of my investigations with an inspiring personal interest.

The acceptance by Professor Kai Siegbahn of a chair of Physics at the University of Uppsala meant a stimulus to nuclear spectroscopy also at this institute. His positive attitude all through has been of major importance for the completion of this dissertation.

For many years the instructive cooperation with Dr. Ingmar Bergström, Nobel Institute of Physics, Stockholm, has been a source of pleasure and encouragement and has, in fact, decisively influenced the direction of my work. Several of the facilities offered me at the Werner Institute are largely a result of the unselfish efforts of Dr. Helge Tyrén, who among other things initiated the construction of the mass separator. Dr. Edvin Arbmán has held a key position in most of the spectroscopic work. His experimental skill and his extreme care in the treatment of data were invaluable assets in our common investigations.

Dr. Peter Hillman improved the English of several of the papers, including this summary, and Mrs. Lotten Borgman has spared no pains in the preparation of manuscripts.

To all contributors, named as well as anonymous, in laboratories, workshops and offices I express my sincere thanks.

GÖRAN ANDERSSON

Uppsala, August 1957

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SUMMARY

At earlier stages in the history of nuclear spectroscopy the objects of study were often randomly chosen for reasons of practical interest and easy availability. The development of high energy accelerators and nuclear reactors, however, created improved possibilities of systematic investigations covering series of related radioactive nuclei in order to reveal regularities in their properties. Such investigations have received a fuller meaning with the advancement of useful nuclear models during the last decade.

The single-particle shell model forms the basis of the present nuclear spectroscopic work, which deals with a region where both protons and neutrons are completing the filling up of their respective shells. It is quite natural that in this region the appearance of metastable nuclear states (isomeric states) should attract special interest because of the direct way of correlating theory and experiment afforded by the gamma-rays of high multipolarity generally emitted in their de-excitation (cf. VI).

In the spring of 1954 a beta-spectrometer study of lead isotopes with mass numbers less than 200 was started at the Werner Institute as a complement to similar work on higher masses carried out at the Nobel Institute of Physics. At present this research programme, which is still in progress, has reached down to Pb^{195} . Simultaneously the decay characteristics of corresponding thallium isotopes have been studied. The nuclei concerned are indicated in the figure below.

	Pb^{195}		Pb^{196}		Pb^{197}		Pb^{198}		Pb^{199}		Pb^{200}	
82	● ○ 17 m EC		● ○ 37 m EC		● ○ 42 m EC, IT	● ○ ≤ 42 m EC, β^+ ?	● ○ 2.4 h EC		● ○ 12.2 m IT	● 1.5 h EC, β^+ ?		21.5 h EC
	Tl^{194}		Tl^{195}		Tl^{196}		Tl^{197}		Tl^{198}		Tl^{199}	
81			● ○ 3.5 s IT	● ○ 1.2 h EC		● ○ 1.8 h EC	● ○ 0.55 s IT	● ○ 2.7 h EC	● 1.8 h EC, IT	● 5.3 h EC		7.4 h EC
	Hg^{193}		Hg^{194}		Hg^{195}		Hg^{196}		Hg^{197}		Hg^{198}	
80	12 h EC, IT	5 h EC		≈ 130 d EC?	40 h EC, IT	9.5 h EC		Stable 0.15 %	23 h EC, IT	65 h EC		Stable 10 %
↑ Z												
N →	113		114		115		116		117		118	

Part of a nuclide chart showing the extension of the present investigations.

●, Decay studied in this work; ○, unknown prior to this work.

It may already be inferred from this figure—a further discussion is given in paper II—that the mass assignment of half-lives and still more so of the numerous

conversion electron lines present in the spectra should meet with considerable difficulties. Thus it very soon proved necessary to tackle this problem with the aid of the mass separator of the institute. The construction of this apparatus and its application to radioactive material are treated in *paper I*.

Abstract.—A small electromagnetic isotope separator has been constructed with special regard to investigations of synchrocyclotron-produced radioactivities. The requirements put forward, including the simultaneous collection at equal focusing conditions of a large fraction of the mass spectrum, were found to be fulfilled by the parallel beam type of magnetic analyser. A brief review of the basic principles of the apparatus is given. Various measures aiming at increased efficiency of the process, improved focusing at higher ion currents, and more stable running conditions are discussed.

The performance of the separator is illustrated by some actual investigations. The applications include mass assignments, β - and γ -ray spectrometry, half-life determinations in the region below 1 ms, measurements of relative yields of spallation and high energy fission products, and "hot atom chemistry".

Paper II gives a general account of the techniques used in sample preparation and spectrometer measurements. The discovery of isomeric states in three odd mass lead isotopes and two probable isomeric transitions in odd mass thallium isotopes may be especially noted among the results of spectroscopic studies.

Abstract.—The following nuclides have been produced by irradiation of Tl in a synchrocyclotron and studied in a β -spectrometer: 12.2 min $\text{Pb}^{199\text{m}}$, 1.5 hr Pb^{199} , 2.4 hr Pb^{198} , 42 min $\text{Pb}^{197\text{m}}$, 37 min Pb^{196} , 17 min $\text{Pb}^{195\text{m}}$, 2.7 hr Tl^{197} , 2.4 hr Tl^{196} and 1.2 hr Tl^{195} . An electromagnetic isotope separator was used to make mass assignments.

All activities except $\text{Pb}^{199\text{m}}$ seem to decay mainly by electron capture. In addition positron branches probably occur in several cases. Fragmentary decay schemes, supported in part by electron-electron coincidence measurements, have been constructed for the odd mass numbers.

A contribution to the knowledge of nuclear level systematics in this region with primary emphasis on the odd mass nuclei is also made.

The indications of isomerism in odd mass thallium isotopes led to a closer investigation of the transitions concerned, partly by means of new experimental methods. The results, establishing the two isomeric states, are reported in *paper III*.

Abstract.—Internal conversion electrons from the isomeric transitions in Tl^{197} and Tl^{195} have been studied in high resolution β -spectrometers. The intensity ratios of the lines, when compared with recent theoretical values, were found to confirm the multipole assignment $E3$ for both transitions. The γ -energies were established as 222.45 ± 0.05 keV ($\text{Tl}^{197\text{m}}$) and 99.1 ± 0.1 keV ($\text{Tl}^{195\text{m}}$).

The half-lives of $\text{Tl}^{197\text{m}}$ and $\text{Tl}^{195\text{m}}$ have been measured as 0.55 ± 0.10 sec and 3.5 ± 0.4 sec, respectively, using rapid chemical techniques and a multichannel method of time analysis. Pulse height spectra of the short-lived activities were found to support the mass assignments.

The search for new even mass isomers in the region of interest has so far failed. An inconsistency in the decay scheme of the earlier known $\text{Tl}^{198\text{m}}$ has been removed, however, as described in *paper IV*.

Abstract.—The energies and intensities of the conversion electrons of the 48 keV γ -ray emitted in the decay of 1.75 h $\text{Tl}^{198\text{m}}$ have been measured in a high resolution spectrometer. The 48 keV γ -ray is converted in Hg, which leads to a revised level scheme of Tl^{198} , the levels being 7+ (543.1 keV), 3- (282.4 keV) and 2- (0 keV). The relative conversion intensities in the L and M subshells, respectively, agree perfectly with those obtained from the *E2* conversion coefficients by Rose *et al.*

Continued measurements have yielded complementary results which have not yet been published. Improvements in the efficiency of the mass separator, making its application more or less a standard procedure in the preparation of spectrometer sources, have greatly promoted this recent work. The new data, in a few cases implying a revision of results reported in papers II and III, are incorporated in paper VI. To avoid confusion, however, the changes will be listed here.

- (1) Half-life of Tl^{196} : 2.4 hr (II) $\rightarrow$ 1.8 hr
- (2) K/L of 425 keV γ -ray following Tl^{196} : 4.4 (II) $\rightarrow$ 2.75
- (3) Energy of γ -ray following $\text{Pb}^{195\text{m}}$: 448 keV (II, III) $\rightarrow$ 383 keV.

About a year ago the need for a compilation and systematic treatment of the ever increasing number of nuclear data in the lead region became apparent. An early product of the surveying work started as a result is included as *paper V*.

Abstract.—A systematic disagreement between experimental and theoretical L conversion ratios has been observed for *E3* transitions in Pb, Tl, Au and Ir. It is shown that multipole mixing cannot explain the discrepancies and that a nuclear size effect seems very improbable.

In *paper VI*, finally, the bulk of pertinent results obtained in various laboratories is recorded and discussed in view of theoretical or semi-empirical predictions. The measurements quoted above have a bearing mainly on chapters 2 and 4 of the survey.

Abstract.—A compilation has been made of experimental data concerning energy levels of nuclei in the *Z*-region 77–84. The data include spin, parity and lifetime of the levels as well as energy and conversion ratios of the multipole transitions involved in their de-excitation. K/L and $(L_I + L_{II})/L_{III}$ conversion ratios are found to agree reasonably well with the values obtained from Rose's tables. Regularities in level separations are pointed out and the appearance of certain levels is discussed on the basis of single-particle shell model predictions. A comparison is made between experimentally determined γ -transition probabilities for *E2*, *E3*, *E4*, *E5*, and *M4* transitions and those calculated from single-particle theory. A marked influence of the magic numbers $Z = 82$ and $N = 126$ shows up both in level separations and in transition probabilities. Special attention is paid to the present theoretical and experimental knowledge of levels in nuclei in the immediate neighbourhood of the double magic Pb^{208} .

